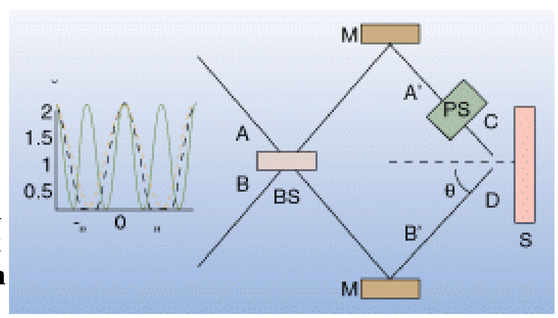
Photonic couples may boost circuit density

OPTICAL LITHOGRAPHY

The trick in surpassing the Rayleigh diffraction limit to further increase circuit density on computer chips may be primarily one of getting the photons to work together. Traditional methods of optical lithography are limited by the wavelength of the light being used. For instance, the use of krypton fluoride (KrF) laser light at 248 nm currently enables the writing of circuit features down to the 180- to 220-nm range with a theoretical lower limit of one-half of the source wavelength (124 nm) as predicted by the Rayleigh diffraction limit.

The Rayleigh limit applies only in the Spartan realm of classical physics, however. So researchers at the NASA Jet Propulsion Laboratory (JPL; Pasadena, CA) and the University of Wales (Bangor) propose to entice classic photons out of their rugged individuality and into a quantum-mechanical world of photonic entanglements that can produce transistor feature sizes measured in tens rather than hundreds of nanometers.[1]

Quantum mechanics makes this possible because of what Einstein referred to as "spooky action at a distance." Two photons can intermingle in such a way that halves their apparent wavelength. The potential result is a corresponding drop in the theoretical limit of feature sizes by a factor of two beneath what either of the individual photons might have achieved—even on a good day, and of course a jump in circuit density by a factor of four. So the new feature-size limit for 248-nm photons would fall almost an order of magnitude, from 124 to 62 nm.



Photons entering ports A and B in inteferometric lithography apparatus negotiate symmetric, lossless beam splitter (BS) prior to reflecting off of mirrors (M) and a phase shifter (PS) in the upper path to ultimately arrive and interfere at the substrate (S). Solid line in graph of deposition rate as a function of phase shift illustrates narrow features obtainable with entangled-photon absorption as opposed to single-photon absorption (dashed line), and uncorrelated two-photon absorption (dotted line).

Ultimately, photonic triangles offer even brighter prospects than photonic couples. Apparent wavelengths and feature sizes would fall by a factor of three and send circuit density skyrocketing by a factor of nine. Unfortunately, such levels of efficiency begin to introduce diminishing returns in classic computer design because the charge barriers would no longer be thick enough to prevent electron tunneling.

The US-UK research team has devised an experimental interferometric lithography system to demonstrate the concept (see figure). It is expected to allow NASA to make its own dense chips fairly soon and may ultimately provide an alternative based on existing optical technology and equipment to the development of vacuum ultraviolet and soft x-ray approaches to smaller circuit size that depend upon smaller source wavelengths.

Several members of the research team also are part of a quantum computing research effort at JPL, which has come up with an idea for an optical quantum gyroscope, also using the concept of photon entanglement The idea of a two-input-port optical gyroscope, invented by group member Jonathan Dowling, is based on the dramatic scaling of phase sensitivity for two properly entangled particles entering a two-port Mach Zender interferometer. In theory, the two-port device would be 108 times more sensitive to rotation than a one-port optical gyroscope and might therefore enable new classes of space missions as well as geological experiments.[2]

"Quantum lithography was actually a spin-off of the quantum gyroscope idea," Dowling said. "No pun intended."

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REFERENCES

1. A. N. Boto et al., Phys. Rev. Lett. 85(13) 2733 (Sept. 25, 2000).
2. See the Web: cism.jpl.nasa.gov/program/RCT/QuantCompUD.html

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